Geospatial Strategy for Estimation of Soil Organic Carbon in Tropical Wildlife Reserve

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Abstract This study focuses on the estimation of soil organic carbon of Sariska Wildlife Reserve. The soil organic carbon is one of the most important issues in the research area of the global carbon cycle as it is the largest terrestrial carbon pool. Geospatial and various forest inventory approaches were used during study for statistical correlation between estimated and predicted value. Remote sensing plays a vital role in spatial data acquisition of the ecosystem carbon dynamics at local, regional, and global scale. The advantage of remote sensing is that it provides synoptic observation, periodical and continuous measurement, and availability of digital data for processing standardization. IRS P6 LISS III data (September 2012) were used to analyze the precise estimation of the percentage of the soil organic carbon associated with organic matter in soil. Statistical analysis was performed for finding the regression curve between the predicted and estimated value of soil

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organic carbon. The results illustrated that the determination of coefficient (r^2) between the predicted and estimated SOC values is found to be 0.708.

Keywords Bare soil index · NDVI · Soil organic carbon · Regression analysis

1 Introduction

Carbon plays an important role in the global carbon cycle (Rani et al. 2011a; Tian et al. 2003; Dong et al. 2003; Bellamy et al. 2005). Carbon in the ecosystem is present in both organic as well as inorganic form. When carbon is present in terrestrial ecosystem associated with the soil then it is called as soil organic carbon (SOC), and SOC turns out to be the largest terrestrial carbon pool playing an important part in the global carbon cycle. Organic carbon plays an important role in the crop productivity, soil type, fertility, physical characteristic of soil etc. Hence, soil organic carbon is the amount of carbon present in the organic matter of the soil while soil inorganic carbon is different from SOC which is held in soil minerals as carbonates. Soil organic matter includes the material of the biological origin present in the soil independent of the origin and state of decomposition of soil (Baldock and Skjemstad 1999; Baldock and Broos 2008). The organic carbon in the soil is present in different types like humus, particulate organic matter, and crop residue due to the varying size of the organic matter (Broos and Baldock 2008; GRDC 2009). Typically organic matter contains 60 % carbon; hence a soil containing 1 % SOC contains around 1.7 % organic matter (Bell and Lawrence 2009). Soil organic carbon plays an important part of the global carbon cycle (Chang 2008). Carbon is continually entering and leaving the soil, therefore soil act as both sink and source. For CO_2, CH_4 and NO_2 it acts as a source while as a sink for greenhouse gasses depending on the land use/land cover (Lal 1999).

The amount or level of carbon is not constant and there is always an exchange of carbon between the various ecosystem and atmosphere (IPCC 2003; Houghton 2005; Hese et al. 2005; Ramankutty et al. 2007; Fung et al. 2007). The land use/ land cover have a direct effect on the carbon exchange between atmospheric and terrestrial ecosystem (Kumar et al. 2012; Tomar et al. 2013; Sharma et al. 2012; Rani et al. 2011b; Houghton and Hackler 1999; IPCC 2003; Righelato and Spracklen 2007; Meyfroidt and Lambin 2008; Cochrane et al. 1999; Houghton et al. 2000; Hirsch et al. 2004; Davidson et al. 2008; Vargas et al. 2008). Amazon forest has been focused by many studies (Cochrane et al. 1999; Houghton et al. 2000; Hirsch et al. 2004; Davidson et al. 2008; Vargas et al. 2008). Due to global warming it has been predicted that there is loss of carbon from soil (Schimel et al. 1994; McGuire et al. 1995). The global scale of organic carbon that is estimated is between 700 and 3,000 PgC (Bouwman 1990) which is based on the approaches like soil groups (Bohn 1976; Buringh 1984) vegetation groups (Ajtay et al. 1979; Bolin et al. 1979). In India the forest soil organic carbon ranges between 5.3 and

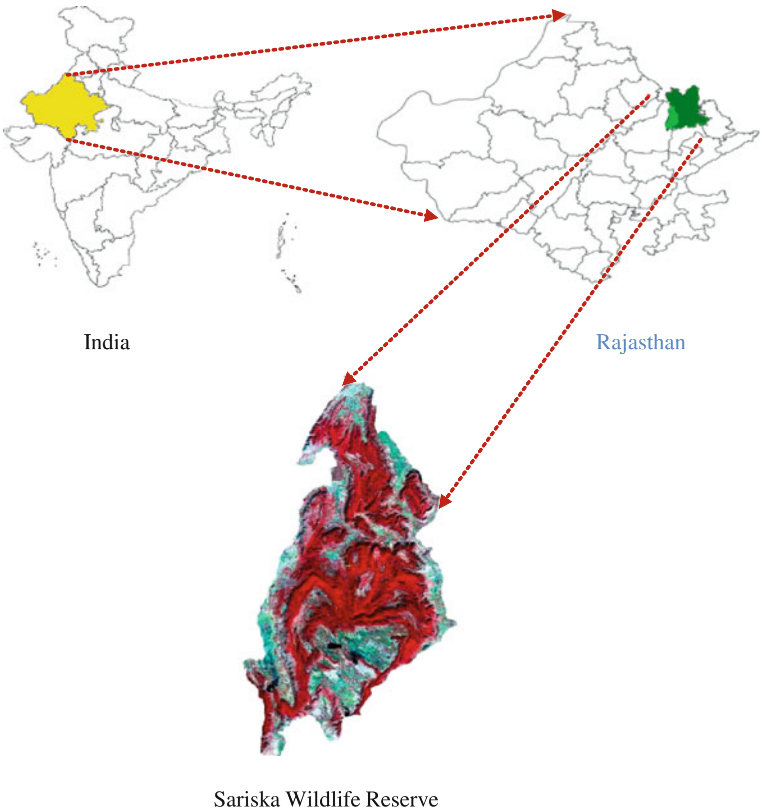

Fig. 1 Location map of the Sariska Wildlife Reserve

6.7 PgC estimated on the basis of global or regional carbon densities (Dadhwal et al. 1998; Ravindranath et al. 1997). The main objective of the study is to analyze the precise estimation of the percentage of the soil organic carbon associated with organic matter in soil and to find the regression curve between the predicted and estimated value of soil organic carbon using statistical analysis.

2 Materials and Methods

2.1 Study Area

The study area (Sariska Wildlife Reserve) lies in the Alwar district, Rajasthan and is located in the older hills of the Aravallies stretched between Mount Abu and Delhi ridge. The study area has geographic extent of 27° 5–27° 33 N latitude and 76° 17–76° 34 E longitudes (Kumar et al. 2013a, b) as shown in Fig. 1. The study

Table 1 Satellite data used in the present study and their specification

Particulars	
Satellite	IRS 1C
Sensor	LISS III
Scale	1:50,000
Band combination	3,2,1
Temporal resolution	5 days
Spatial resolution	23.5 m
Year	September 2012

site covers an area of 866 km^2 including 492 km^2 of the notified Sariska Wildlife Reserve and 374 km^2 of adjoining area of Alwar, Rajgarh and Sariska forest ranges transferred and included in the Sariska Wildlife Reserve. Total forest area under the Sariska Wildlife Reserve consists of 49,199.54 ha in which there are 25 forest blocks, out of which 12 are reserved forest and 13 are preserved forest. The type of the soil and soil characteristics varies according to the type of underlying rocks. The soil type map generated in the study area shows that it contains the soil like loamy, coarse loamy, fine loamy and sandy soil. Major part of the area is covered by the rocks like quartzite, conglomerates, grits, limestone, phyllites, granites and schist. Ancient crystalline and metamorphic rocks with gneisses and schist are generally covered by red sandy soil, which is generally poor in nitrogen, phosphorus and humus contents and are alkaline in nature. There are comparatively rich fertile and dark colored soils in plants and valleys. The soils resulting from the weathering of schistose rocks vary from sandy to heavy loam depending upon the amount of quartzite present in the parent rocks.

2.2 Data Used

The satellite and ancillary data used in the study includes auxiliary and primary data. Primary data were obtained during the field visits by surveying and measuring the study area. The IRS P6 Linear Imaging Self Scanning Sensor III satellite images were used in the study for soil carbon. The specifications of LISS III sensor are illustrated in Table 1.

2.3 Image Interpretation

In the present study, satellite imagery and toposheet acquired from the survey of India (SOI) were used. Digital preprocessing techniques were applied for identifying the different classes and feature in the imagery. The rectification and geo-referencing of satellite imagery was performed using ERDAS IMAGINE 2011©software with reference to toposheet. The 4 bands corresponding to Near

Infra-Red (NIR), Red, Green and Blue of LISS III imagery helped in identifying image characteristics and ground features after image processing technique (Kumar et al. 2013a, b; Kumar and Tomar 2013). Ground truthing of the study area helped out in identifying the different features and land use/land cover correctly.

2.4 Estimation of Soil Organic Carbon

Plot layout during field investigation needs a lot of precautions for collecting samples. We kept in mind all major precautions to be taken during plot layout in the field. Firstly, on hills chooses any aspect and all the plots need to be in same aspect; Second, avoid any major stream inside the plot i.e. the plot can be adjusted to that plot is laid on one side of the stream within the frame of 31.62 × 31.62 m; Third, we need to fix the direction/side of plot, i.e. left or right side of the direction, which is followed uniformly; Fourth precaution is to keep all the baggage outside the proposed plot. This is important to avoid trampling of the herbaceous flora of that corner. Organic soil carbons in each soil sample (humus 0–15 cm and mineral 15–30 cm) were determined using the procedure given by Walkley-Black (1934). In this reaction, carbon is oxidized by the dichromate ion. The excess dichromate ion is then back titrated with ferrous ion (Walkley 1947; Jackson 1958). First of all, 30 soil samples were collected from the Sariska Wildlife Reserve. The sampler chosen in this study is having 3.8 cm radius with soil depth of 5 cm. Every soil sample taken varies in their weight (gm) with a heavy bulk density of approx. 1.4 g/m^3.

During laboratory analysis, 1.00 g soil was taken into 500 ml Erlenmeyer flask. Thereafter, 10 ml of 1N potassium dichromate solution was added to it. Further, 20 ml of sulfuric acid was added to it and mixed by gentle rotation for 1 min, taking care to avoid throwing soil up onto the sides of the flask. Then, it was allowed to stand for 30 min. The solution was diluted to 200 ml with deionized water. Again, 10 ml phosphoric acid, 0.2 g ammonium fluoride, and 10 drops diphenylamine indicator were added to the solution for additional test. The solution was titrated with 0.5N ferrous ammonium sulfate solution until the color changes from dull green to a turbid blue. The titrating solution was added drop by drop until the end point is reached when the color shifts to a brilliant green. Similarly, blank control sample was prepared in the same manner. One duplicate sample and one quality control sample was prepared with each set of samples analyzed. The percentage soil organic carbon is shown in Table 2.

$$\%\ Soil\ Organic\ Carbon = 10[1(S \div B)] \times 0.67 \quad (1)$$

where S = Sample titration, and B = Blank titration

Table 2 Soil organic carbon

Plot no.	Sampler radius (cm)	Soil weight (gm)	Bulk density (g/m^3)	% SOC	SOC (t/ha)
1	3.8	360	1.58	0.68	5.396
2	3.8	320	1.41	0.98	6.912
3	3.8	342	1.50	1.1	8.292
4	3.8	348	1.53	1.12	8.591
5	3.8	347	1.52	1.21	9.255
6	3.8	362	1.59	1.23	9.815
7	3.8	322	1.41	1.32	9.369
8	3.8	330	1.45	1.26	9.165
9	3.8	306	1.34	1.21	8.161
10	3.8	315	1.38	1.32	9.165
11	3.8	300	1.32	1.6	10.580
12	3.8	344	1.51	1.58	11.981
13	3.8	325	1.43	1.6	11.462
14	3.8	356	1.56	1.79	14.047
15	3.8	345	1.52	1.86	14.145
16	3.8	349	1.53	1.96	15.078
17	3.8	351	1.54	1.98	15.319
18	3.8	349	1.53	2.01	15.463
19	3.8	342	1.50	2.06	15.530
20	3.8	352	1.55	2.08	16.139
21	3.8	312	1.37	2.11	14.511
22	3.8	326	1.43	2.13	15.306
23	3.8	356	1.56	2.13	16.715
24	3.8	321	1.41	2.2	15.567
25	3.8	312	1.37	2.2	15.130
26	3.8	324	1.42	2.2	15.712
27	3.8	326	1.43	2.3	16.528
28	3.8	365	1.60	2.62	21.080
29	3.8	363	1.60	2.43	19.444
30	3.8	398	1.75	2.54	22.284

3 Results and Discussion

3.1 Land Use Land Cover Classification

Land use is the area which is being used by men for its use and land cover is the area where natural resources have no disturbance or human interference. Land use/ Land cover (LU/LC) was prepared which was validated with the accurate GPS points taken during field visits. The leica GPS was used to acquire the positions of the point samples, having accuracy of 10 m. The GPS point samples were post processed to match the accuracy with imagery. In the present study, the site classified as land cover includes dense forest, degraded forest, open forest, non forest while land use includes water body, settlement, road and drainage (Fig. 2).

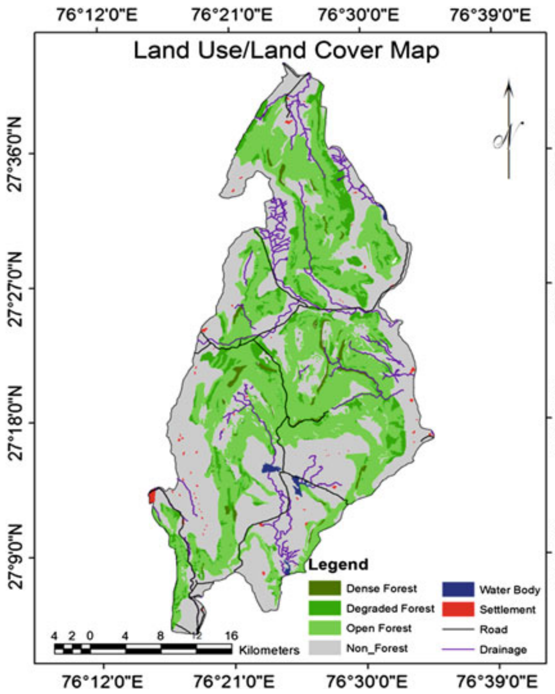

Fig. 2 LU/LC map of the study area

Table 3 Calculated area of Sariska Wildlife Reserve LU/LC classes

LU/LC classes	Area (km^2)	Area (%)
Dense forest	14.191	1.601
Open forest	468.467	52.856
Degraded forest	97.708	11.024
Non forest	292.353	32.986
Settlement	4.293	0.484
Water body	9.293	1.049
Total area	886.305	

The total area under LU/LC was found to be 886.305 km^2. Table 3 shows the area covered by different type's i.e. dense forest, open forest and degraded forest, occupying 1.6, 52.85 and 11.02 % of the area respectively. The lowest area was covered by settlement (0.484 %) and water body (1.049 %).

3.2 Bare Soil Index

Bare soil can be defined as the soil and sand on the earth's surface not covered by any grass, wood chips, any live ground covers, artificial turfs and similar covering. Bare soil index (BSI) estimates the value of bare soil in the study area as shown in

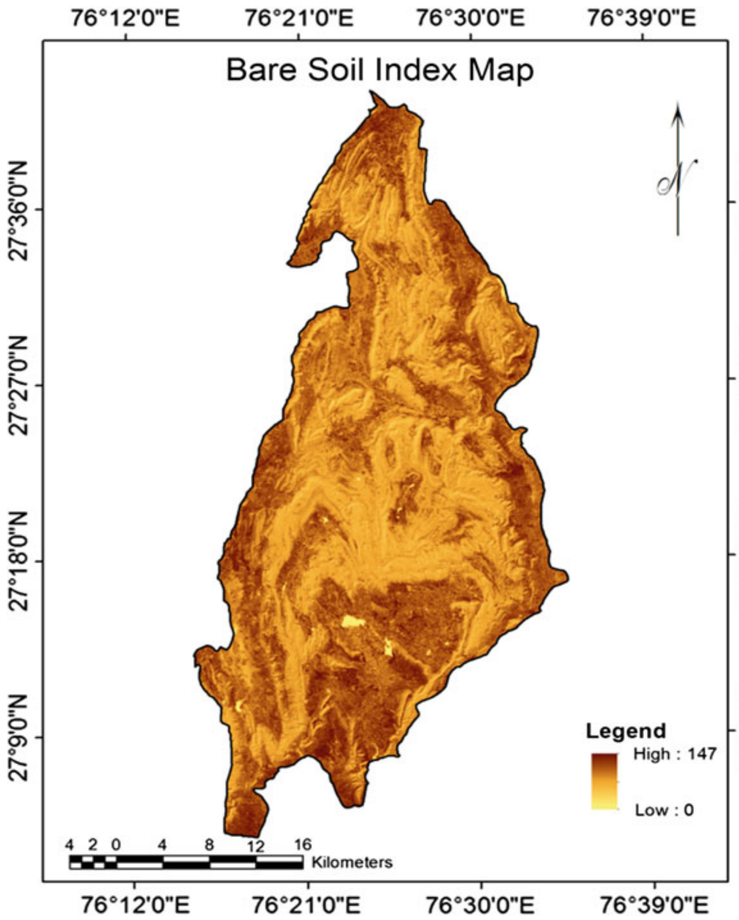

Fig. 3 Bare soil index map of the study area

Fig. 3. BSI helps in separating the vegetation with different background features. Digital classification of satellite data are based on spectral signature and are reported to be more precise. So BSI reduces the effects of bias and assist in the extraction of the significant features of a specific ground object. Hence, the present approach isolates vegetation using BSI indices. The formulae used for calculating the bare soil index is given as (Rikimaru et al. 2002).

$$BSI = [(B5 + B3) - (B4 + B1)]/[(B5 + B3) + (B4 + B1)] \times 100 + 100;\ 0 < BI < 200 \quad (2)$$

The range of BI is converted within 8 bits range.

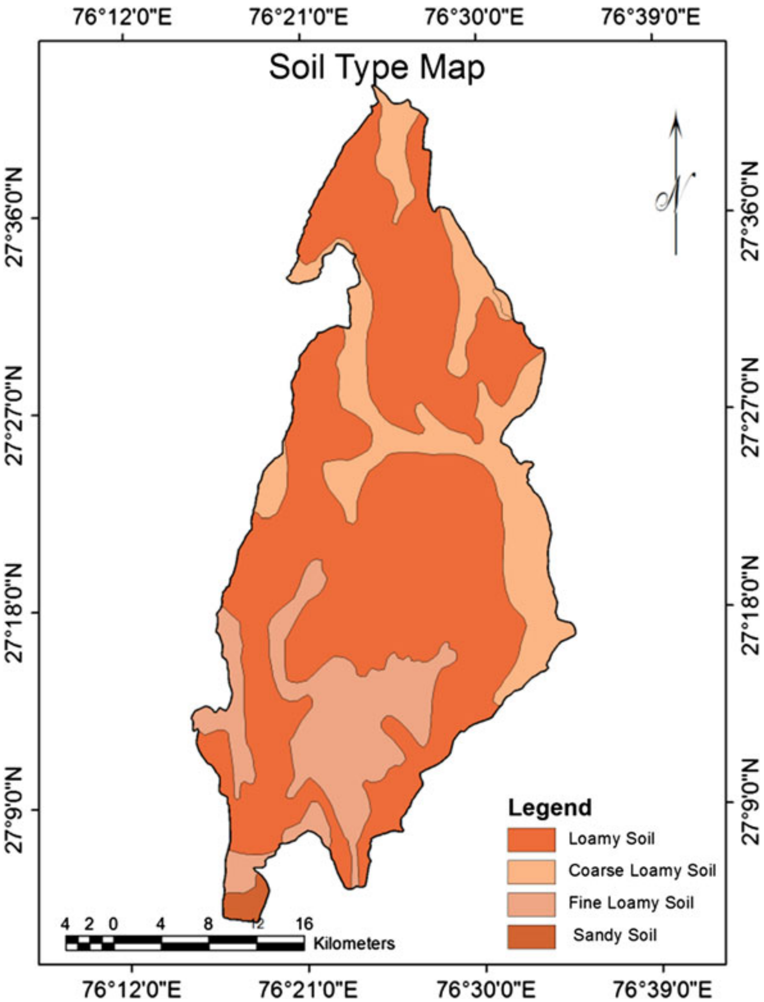

Fig. 4 Soil Type map of the study area

3.3 Soil Type Map

Sariska Wildlife Reserve soil properties are problematic to measure, but can be projected with acceptable accuracy from other soil parameters of the same location. Spectral characteristic pattern of soil is generally overseen by a many number of aspects like soil color, texture, salinity, structure, mineralogy, moisture content, macro and micro organic matter. The literature review designates the major soil properties showing relatively high correlation with remote sensing images. These soil properties are soil moisture, total organic carbon, chemical and physical

Table 4 Estimated and predicted SOC

Plot no.	Predicted SOC	Estimated SOC
1	0.293	5.396
2	0.255	6.912
3	0.233	8.292
4	0.278	8.591
5	0.235	9.255
6	0.279	9.815
7	0.485	9.369
8	0.251	9.165
9	0.351	8.161
10	0.360	9.165
11	0.380	10.580
12	0.448	11.981
13	0.434	11.462
14	0.437	14.047
15	0.444	14.145
16	0.455	15.078
17	0.487	15.319
18	0.456	15.463
19	0.466	15.530
20	0.471	16.139
21	0.458	14.511
22	0.480	15.306
23	0.478	16.715
24	0.490	15.567
25	0.490	15.130
26	0.486	15.712
27	0.480	16.528
28	0.506	21.080
29	0.515	19.444
30	0.530	22.284

properties of soil, salinity clay, silt and sand contents. The soil type map was prepared using ground data and GIS with reference to National Bureau of Soil Survey shown in Fig. 4.

As the above figure depicts about the extent and area covered by the soil type, we can see that the loamy soil covers a large part of the area in the core heart whereas the sandy soil covers least only in the south region. The other two types lies in buffer region such that coarse loamy has its higher percentage in north and north–west region and fine loamy in south parts.

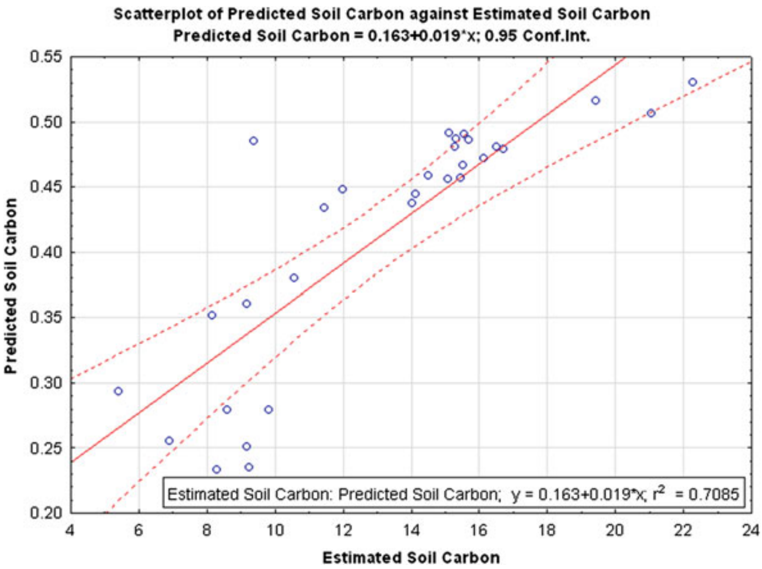

Fig. 5 Regression analysis between estimated and predicted SOC

3.4 Soil Organic Carbon and Regression Analysis

In the present study, R^2 values are used for determination of the linear model. R^2 is the coefficient of determination which has long been used to compare the different models in past study. It was observed that linear equation gives the results which is 0.708. It was observed that there is a positive correlation between the estimated and predicted value. Total carbon is determined using band data and NDVI generated using band data (Table 4). The determination of coefficient (r^2) between the predicted and estimated SOC values is found to be 0.708 (Fig. 5). Thus, carbon maps (Fig. 6) are generated using linear equations.

$$SOC = 0.163 + 0.019 \times NDVI \tag{3}$$

where SOC = Soil organic carbon, and NDVI = Normalized Difference Vegetation Index.

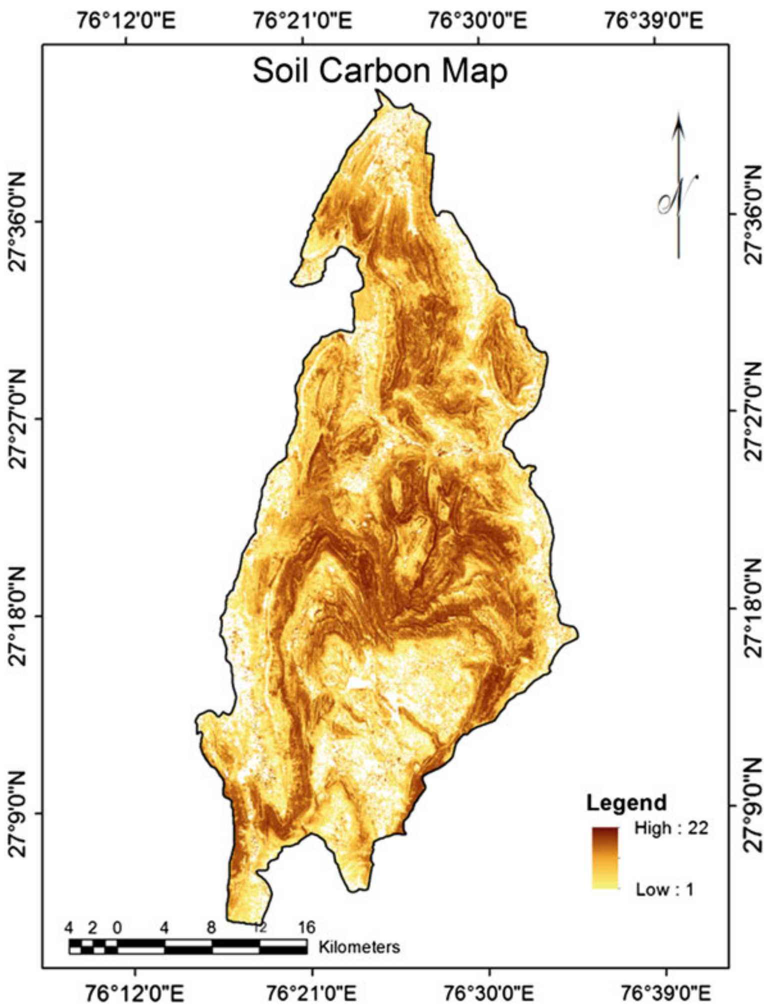

Fig. 6 Soil Carbon map of the study area

4 Conclusion

Linear model was used in the present study to determine the soil condition of the region. R^2 (coefficient of determination) has long been used to compare models for forest parameters like tree volume, above ground biomass, leaf area index and heights (Segura and Kanninen 2005; Lu et al. 2012; Zhao et al. 2009; Samalca 2007). However, for models with different set of variables, R^2 gives misleading results. Total carbon can be determined forming spectral modeling using band data and NDVI generated from the band data. Carbon maps are generated using the linear equations. The estimated values generated from the field study correlates with the predicted value generated from spectra spectral modeling.

This collected data containing the information on location, soil type, texture, measured/estimated bulk density helps in estimating the soil organic carbon present in the soil of Sariska Wild life reserve for depth of 5 cm. The estimated SOC densities were combined with the remote sensing. The study exposes the approaching of LISS III image in estimating SOC for the heterogeneous tropical forest. The extraordinary positive correlation between the estimated SOC directly from field parameters and predicted SOC from spectral band information demonstrates the fact that NDVI can be considered to be an effective spectral vegetation index to estimate SOC. Linear models also showing comparable results and can be considered as standard.

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